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DESIGN AND CONSTRUCTION OF THE TRITIUM SYSTEMS TEST ASSEMBLY

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ABSTRACT

The Los Alamos Scientific Laboratory has been funded by the Office of Fusion Energy, U.S. Department of Energy to design, construct and operate the Tritium Systems Test Assembly (TSTA). The objective of TSTA is to develop those aspects of tritium technology related to the fuel cycle for fusion power reactors and to develop the environmental and personnel safety systems required for such a tritium facility. The TSTA schedule calls for construction to be completed and the facility to be operational by the end of FY-1981. The project is now somewhat more than halfway through the design-construction phase and is currently on schedule for the 1981 operational milestone. In this paper the current status of the major subsystems will be discussed. The subsystems to be discussed include the; Vacuum Facility; Fuel Cleanup; Isotope Separation; Transfer Pump; Emergency Tritium Cleanup; Tritium Waste Treatment; Tritium Monitoring; Secondary Containment; and, the Master Data Acquisition and Control System.

INTRODUCTION

In 1977 the Office of Fusion Energy, US Department of Energy funded the Los Alamos Scientific Laboratory (LASL) to design, construct and operate the Tritium Systems Test Assembly (TSTA)[1]. The principle objectives of the TSTA Project are: (1) demonstrate the fuel cycle for fusion power systems; (2) develop, test, and qualify equipment for tritium service in the fusion program; (3) develop and evaluate personnel and environmental protection systems; (4) provide a facility that will yield a reliable data base for tritium handling systems for future fusion facilities; (5) demonstrate long-term safe handling of tritium with no major releases or incidents; (6) investigate and evaluate the response of the fuel cycle and environmental packages to normal, off-normal, and emergency situations; and (7) develop tritium compatible components having long term reliability.

The TSTA schedule calls for construction to be completed and the facility to be operational by the end of 1981. An existing building at LASL has been modified to house the TSTA. The modifications to this building have now been completed, Fig. 1, and the installation of equipment for specific subsystems is now underway. The project is now somewhat more than halfway through the design - construction phase and is currently on schedule for the 1981 operational milestone. The goal of the TSTA project is to provide an extensive data base which will be available to the designers of the first large-scale deuterium-tritium burning fusion machine. This may well be the Engineering Test Facility (ETF) or the International Tokamak Reactor (INTOR). The ETF concept is currently being developed through the ETF Design Center at Oak Ridge. Optimistic estimates indicate that an ETF could be operational in the 1991-1992 time period. This would require a detailed design phase in the 1983-1987 period. For TSTA to make a significant contribution to the ETF data base requires that TSTA become operational by the end of 1981. The INTOR project is a joint international effort involving the United States, Japan, Russia and the European Community. The goals and objectives of ETF and INTOR are quite similar. Currently, the four INTOR participants are engaged in a series of workshop and conceptual design meetings. Realistically, one cannot predict that INTOR could be built on a time scale any more optimistic than that being discussed for ETF. Therefore, the TSTA schedule as currently planned will provide the necessary data base for INTOR.

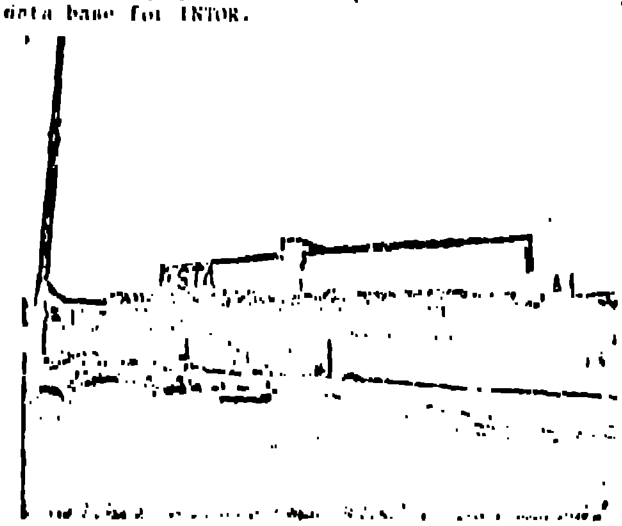

Fig. 1. The TSTA Building.

*This work is supported by the Office of Fusion Energy, U.S. Department of Energy.

In this paper the current status of each of the major subsystems will be discussed along with some discussion of the current design of the various subsystems.

SYSTEM DESCRIPTIONS

The TSTA will consist of a large, interactive, gas, loop, Fig. 2, which can simulate the proposed fuel cycle for a fusion facility. There will, of course, not be a reactor torus, but this will be simulated by a vacuum vessel into which is introduced gas mixtures at the composition and pressures predicted for an actual reactor torus at the end of a burn cycle. This gas mixture, primarily $(D,T)_2$ containing a variety of impurities, must be evacuated through a prototypical vacuum system, the impurities removed from the $(D,T)_2$ and isotopic separation performed to produce D_2, T_2 and DT. These resultant gases will then be the fuel components injected into the reactor (vacuum vessel) in anticipation of the next burn cycle. The gas loop is designed to handle up to 360 g moles per day of DT. This flow will provide cycle operating experience on a scale that is similar to that currently being considered for ETF and INTOR. Along with the gas loop are all of the safety and experimental systems associated with such an extensive tritium facility. To accomplish the goals of the program will require an on-site tritium inventory of approximately 150 g. The design and current status of the major TSTA subsystems are discussed below.

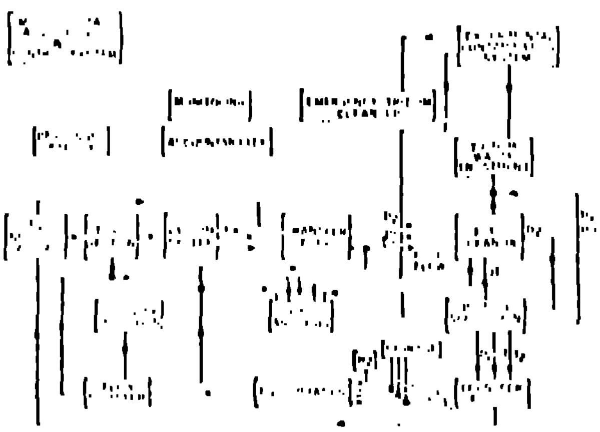

Fig. 2. The TSTA Process Loop showing Subsystem Interactions

Vacuum Facility (VAC) This system consists of a large vacuum vessel with associated duct leading to the vacuum pumps being evaluated for use in the fusion program. Three cryo based vacuum pumps are being evaluated at TSTA as candidates for the primary vacuum pumps on a fusion reactor. These are all "compound" pumps in that they are two stage. In all three pumps the first stage is cryocondensation of hydrogen on a metal surface cooled to or near liquid helium temperatures. This will pump all of the hydrogen isotopes, but does not pump helium. In the first such pump, Fig. 3, built by LASL[2], the helium is pumped by cryosorption on a molecular sieve surface cooled to liquid helium temperatures. A second pump, being developed at Brookhaven National Laboratory[3], will pump helium by cryosorption on a charcoal surface cooled to liquid helium temperatures. The third pump, being developed at the Lawrence Livermore Laboratory, will pump helium by cryotrapping. A pump very similar to that being built for TSTA by LLL has been described by Batzer, et al[4]. Here a fine spray of argon gas will be injected into the pumping area and will condense as a solid on a helium cooled metal surface. The helium gas will be trapped, thus pumped, by the argon ice formed on the cold surface. To date only the first of these three pumps has been built and is currently undergoing tests. With this pump it has been demonstrated that a compound pump can simultaneously pump helium and hydrogen isotopes. The separation of hydrogen on the condensation panel from helium on the cryosorption panel is extremely sharp. This separation can be maintained by careful temperature and pressure control during regeneration. The helium panel is first regenerated and the cryocondensation panel can then be warmed to remove hydrogen from the pump. Complete evaluation of this pump plus evaluation tests on the remaining two pumps will continue.

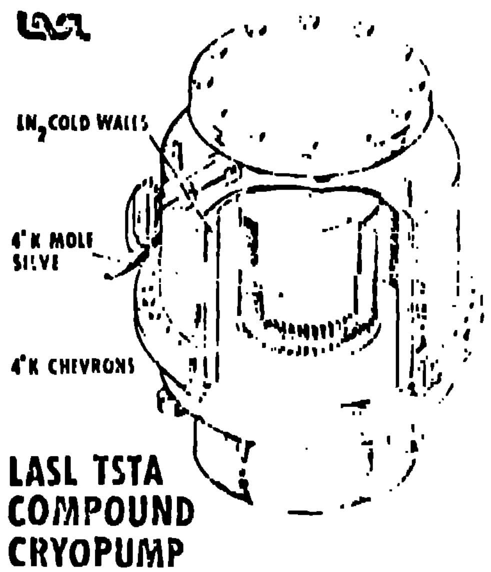

Fig. 3. Drawing of the LASL TSTA Compound Cryopump

The TSTA vacuum facility will also include a [illegible] regeneration system to be used during regeneration of the cryopump. The regeneration system has been described by [illegible] and Walthers[2].

Fuel Cleanup (FCU) The primary function of the FCU is to separate all of the other atoms present from the hydrogen isotopes in the gas stream from the Vac facility. This step is essential; if other molecular species such as tritiated water, methane or ammonia, argon, etc., were present in the hydrogen isotope stream they would freeze out and plug the low temperature distillation columns of the Isotope Separation System. The FCU must not only separate $(D,T)_2$ and (H,D,T) from the reactor of offgas contaminants, it must also recover as $(H,D,T)_2$ all of the hydrogen isotopes that are chemically combined with other atoms in the reactor offgas, i.e., $C(H,D,T)_4$, $N(H,D,T)_3$ and $(H,D,T)_2O$. Table 1 shows the predicted feed stream flows to the FCU. The hydrogen molecules can be separated from the other molecular species by adsorbing the impurities at 75 K on a 5A molecular sieve. (The tritiated ammonia and water are frozen out of the offgas prior to entering the molecular sieve). The need to regenerate the molecular sieve requires additional processing. These considerations have led two proposed processing schemes. In one system a hot metal bed (Uranium at 1170 K) front-end removes carbon, nitrogen and oxygen in the feed stream by conversion to uranium carbides, nitrides and oxides and releasing the associated hydrogen isotopes as gas. The uranium will periodically become saturated with impurities and have to be replaced. The second front-end system has a catalytic reactor to convert any free oxygen in the feed stream to $(D,T)_2O$ which is then removed along with the ammonias and carbon dioxide by freezing. These two front-end packages would be operated alternatively. Each front-end system is backed by a cryogenic package where argon and any other trace impurities are removed by adsorption on molecular sieve, thus producing a pure stream of hydrogen isotopes to feed the isotope separation system. The FCU is discussed in detail in a separate paper at this conference[5].

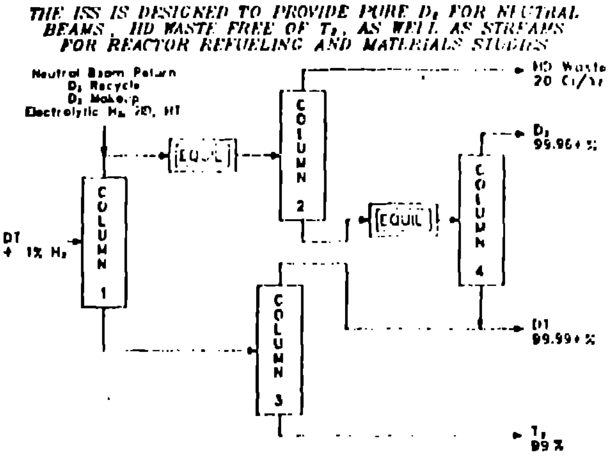

Fig. 4. Flow Diagram for the ISS Distillation Column

two systems for storing gas evolved from vaporization of the hydrogen liquids. First, a large surge tank is provided that will allow the total contents of the ISS to be stored as a gas at a pressure less than 100 psi. Second, each column has access to a vessel filled with uranium powder which can hydride the gaseous hydrogen isotopes and thus store them as solids. The contents of each column can thus be stored individually during periods of planned shutdown. The ISS is totally under double containment. The distillation system is now essentially fabricated and the initial performance tests on the columns will begin in early May 1980 with delivery to TSTA scheduled in June 1980.

Table 1
Impurity Gas Load for TSTA
(based on 360 g moles/day DT flow)

Element	Mol %	Species	Grams/day
He	2 – 20	He	29 – 290
H	1	HD, HT, H_2	7
C	0.02 – 0.1	$C(DT)_4$, $C_2(D,T)_2$, CO_2	1.7 – 9
N	0.1	$N(D,T)_3$, N_2, CN, NO_x	10
O	0.5	$(D,T)_2O$, CO_2, O_2	57
Ar	0.00006 – 0.05	Ar	0.17 – 14

Isotope Separation System (ISS) At TSTA cryogenic fractional distillation[6,7] is being used for hydrogen isotope separation. A system utilizing four interlinked columns with chemical equilibrators located between columns 1 and 2 and between columns 2 and 4, Fig. 4, has been designed. The system is sized to handle the full flow appropriate to ETF or INTOR; i.e. 360 moles DT per day. It will also handle the simulated flow from the neutral beam channel vacuum pumps (∿ 275 moles D_2 per day). The figure shows the flow paths and purities of the major component in each of the four output streams. Refrigeration will be supplied by a central cryogenic refrigerator providing helium gas at ∿20 K. In event of loss of refrigeration the ISS contains

Transfer Pumps (TPU) The transfer pump at TSTA will provide circulation and transport for mixtures of hydrogen and helium isotopes from one portion of the flow loop to another. An early decision was made that all process wetted components of transfer pumps will be of metal or inert carbon construction. Mechanical motion of internal parts is transmitted by flexible metal membranes (diaphragm or bellows), by magnetic transmission (canned motors), or by magnetically confined sealants (Ferrofluids). A pump which meets most of the TSTA gas transfer requirements is a metal bellows pump (Model MB 601, manufactured by Metal Bellows Corp., Sharon, MA) which incorporates a replaceable all metal [illegible] valve assembly designed and tested at LASL. The basic pump has two heads, which can be plumbed to operate in series, in parallel or independently. Figure 5 is a conceptual drawing of the TSTA metal bellows transfer pump housed in the secondary containment glove box. Other pumps

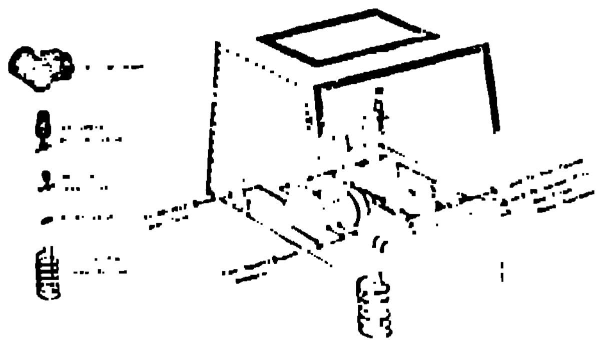

Fig. 5. Drawing of a Transfer Pump Unit with Secondary Containment

under consideration include an all metal bellows sealed stainless steel-scroll pump and a canned-motor, Ferrofluid-sealed Roots blower. These pumps have all been procured and are now being tested and installed at TSTA.

Emergency Tritium Cleanup (ETC) This system will provide processing of all of the air in TSTA in the event of a gaseous tritium release to the facility[8]. The system will recover most of the released tritium, thus reducing losses and environmental impact. The TSTA cell contains 3000 m^3 of building atmosphere which would become contaminated with tritium in the event an accident caused the primary and secondary containments to be breached. The flow rate through the ETC is 0.65 m^3/sec. The ETC will be an automatically actuated room air detritiation system based on a precious metal catalytic recombiner where hydrogen isotopes are oxidized to water. The water is then collected, partly as liquid water and by adsorption on molecular sieve beds. The flow path for gas through the ETC is shown in Fig. 6. A 100 g T_2 spill into the facility would give an initial concentration of ~355 Ci/m^3 in the cell. The ETC is designed to reduce the room level to 40 x 10^{-6} Ci/m^3 within 24 hours. The ETC has been designed at TSTA with individual components purchased by LASL. The assembly and installation of these components, including instrumentation, is being done by LASL. The ETC equipment has all been procured and the installation of this system is nearly completion.

Tritium Waste Treatment (TWT) This system provides routine processing of all gaseous effluents generated at TSTA to remove tritium from these effluents before they are released to the environment. This system is based on the design of a similar system which has been operating for five years[9] and which is discussed by Nasise[10] in a separate paper at this conference. The TWT is designed to operate at a flow rate of 15 or 60 scfm depending on the gas load at the TWT inlet.

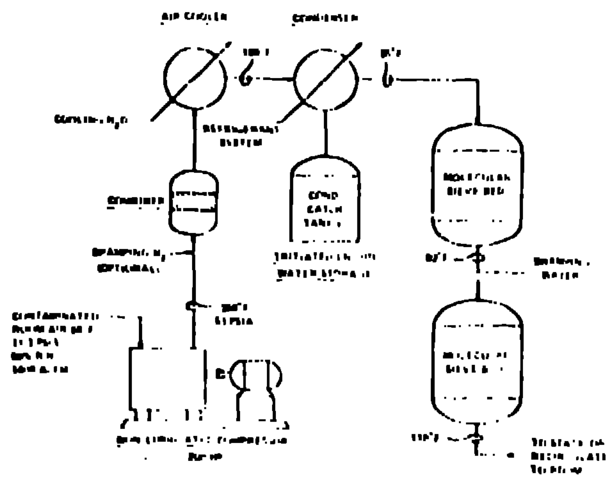

Fig. 6. Flow Diagram for the Emergency Tritium Cleanup System

The TWT is a computer-actuated and controlled tritium removal system that operates by the catalytic conversion of all hydrogen isotopes in the input stream to water and organic materials to water and carbon dioxide. Oxygen level will automatically be maintained in the system at sufficient levels to ensure catalytic conversion of all hydrogen isotopes to water. Water generated by these processes will be adsorbed on molecular sieve. The remaining gaseous effluent will then be discharged to the atmosphere through the building ventilation system after it has been determined that the tritium has been removed to the as low as practicable level. Figure 7 is a flow chart for the TWT. As with the ETC, the TSTA staff has designed the TWT, purchased individual components for assembly into the final system. This was preferred rather than buying a preassembled TWT package from a single supplier. All of the components for the TWT are now installed at TSTA. Final piping and electrical connections are being made and the system will then be ready for testing.

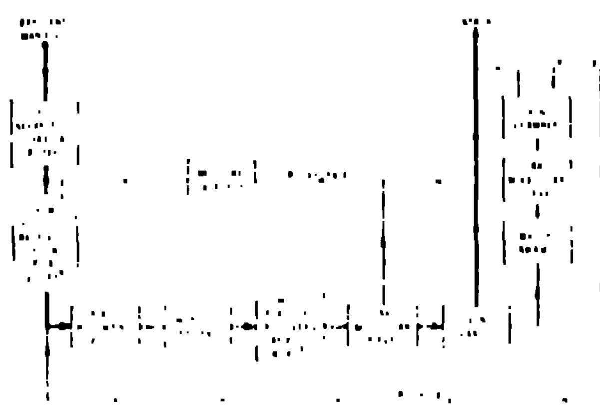

Fig. 7 Flow Diagram for the Tritium Waste Treatment System

Tritium Monitoring (TM) Tritium monitoring instrumentation will perform several key functions including quantitative determination of stack releases, assurance of personnel safety, initiation of cleanup of experimental rooms and secondary containment volumes following tritium releases, monitoring and controlling the operation of the main process loop and the cleanup systems, and monitoring the performance and results of the experimental contamination studies program. Most of the monitors will be flow-through ionization chambers with redundancy provided for critical situations. The monitors will, for the most part, be similar to currently available standard tritium instrumentation. Major differences may include special sensors (e.g., plastic scintillators) required for line monitors and alpha-rejection circuitry to increase sensitivity and selectivity. All of the monitoring equipment for TSTA has now been defined[11] and is being procured and installed at this time.

Secondary Containment (SEC) The philosophy at TSTA is to doubly contain all components of the primary fuel process loop wherever tritium could conceivably be released in multicurie quantities, posing significant hazards to workers and the environment. Secondary containment concepts being applied to TSTA include double-wall piping and components, gloveboxes or other large volumes housing tritium-wetted components and the use of integral vacuum jackets around cryogenic components. The vacuum jacket helps provide thermal isolation as well as providing secondary containment. Initial plans did not call for secondary containment of the VAC facility as it was felt that the primary containers (vacuum tank and cryogenic pumps) could be designed with an adequate safety factor to virtually eliminate the risk of a release. This decision is currently being reviewed and concepts for providing secondary containment of VAC are being investigated. In all other subsystems of the main fuel process loop the secondary containment is being designed and installed with the subsystem.

Experimental Contamination Studies (XCS) This will be a small laboratory at TSTA dedicated to the study of several aspects of tritium contamination/decontamination. Included are plans to study the performance and efficiency of a small tritium cleanup, gas detritiation system; to study surface contamination, outgassing and permeation properties of construction materials (wood, concrete, steel, etc.) and surface coatings (epoxy paint, latex paint, etc.); to study contamination and outgassing properties of metals, gloves and plastics used in tritium containment systems; to study the relationship between total tritium in a material and amount measured by surface survey probe and by wiping removable tritium; to study methods of decontamination; and, to study gas conversion rate of T_2 and DT to the oxide forms during realistic release situations. The XCS will be housed in a separate laboratory room at TSTA. The room is designed so that it can be completely sealed-off from the rest of the facility. This room can then be used for evaluation of the ETC by deliberately releasing tritium into the sealed room. Under these conditions the ETC, operating at 25% of normal speed will be used to detritiate the XCS room. This will be very helpful in evaluating large detritiation systems such as the ETC. When the XCS experiments have generated sufficient data on surface coatings for tritium facilities the XCS room will be refinished to provide the best apparent surface coatings on walls, ceilings, etc. The tritium release/cleanup experiments will then be repeated by again releasing tritium into the sealed room and using the ETC for cleanup. These experiments will be very valuable in choosing construction materials, surface coatings, etc. for future fusion systems. The equipment for this laboratory is currently being designed and procured and will be installed and checked out in 1981.

Master Data Acquisition and Control (MDAC) TSTA is designed to be a computer controlled system and will not operate fully unless MDAC is operational. Each subsystem will be able to be tested without MDAC if necessary, however, at the present time it is anticipated that the process loop of TSTA will not operate without MDAC control. MDAC will be designed to incorporate features which will minimize potential hazards to operational personnel, the general public and equipment. All identified hazardous situations will be monitored and controlled by hard wired interlocks and backed up by the monitoring of MDAC. The MDAC will monitor all radiation detectors and take appropriate action (give alarms, notify for evacuation of building, etc.) if unsafe conditions are detected. The subsystems of TSTA will be self-protecting to insure against computer error resulting in a hazardous operating mode. Some equipment which can potentially lead to a hazardous situation during malfunction will have built-in, absolute limit protection to insure against both local manual and remote computer errors that can result in unsafe or hazardous situations. Checks of equipment performance will be done in software. The MDAC will also monitor input commands from critical locations to insure that neither operations by unauthorized personnel nor errors by authorized operators will cause a hazardous situation. Validation checks on computer commands will be performed in software. The computer, a Data General Eclipse, has been purchased and is installed and operating at TSTA. Control software is currently being developed. The MDAC will utilize a CAMAC interface system. The computer system is operated through an Uninterruptable Power Supply. An Emergency Generator Set will be available to operate the MDAC and critical components of the major subsystems in the event of a loss of commercial power.

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